WAVELENGTH MONITORING APPARATUS

BACKGROUND OF THE INVENTION

The present invention relates to a wavelength monitoring apparatus used in an optical communication system, an optical measuring system, or the like.

5   In recent years, increase in capacity of an optical fiber communication network has been strongly demanded because of the rapid advance of popularization of Internet. Development of wavelength division multiplexing (WDM) communication as means for increasing the capacity has been advanced rapidly. An optical

10   function device such as an optical demultiplexer, a filter or an isolator good in wavelength selectivity is necessary for such WDM communication because beam components with slightly different wavelengths are used for transferring different kinds of information individually. It is a matter of course that the

15   aforementioned function device is strongly demanded in mass-production efficiency, reduction in size, integration in density, stability, and so on.

In wavelength division multiplexing optical communication, a beam source for emitting beam with a plurality of wavelengths

20   is required because optical signals with a plurality of wavelengths multiplexed artificially are used. In the initial stage of wavelength division multiplexing communication, a large interval

was provided between wavelengths such as 1.3 μm and 1.55 μm. With the increase in communication capacity in the recent years, however, in the vicinity of 1.55 μm, wavelength multiplexing in a frequency interval of 100 GHz (wavelength interval of about 0.8 nm), and further, wavelength multiplexing in a frequency interval of 50 GHz (wavelength interval of about 0.4 nm) have been required, and practical use of such wavelength multiplexing has been already advanced. Hence, as the wavelength interval is reduced in the aforementioned manner, wavelength stability of a semiconductor laser used as a beam source becomes important.

Because the oscillation wavelength of the semiconductor laser is remarkably affected by temperature, a wavelength monitoring mechanism is generally provided. A monitoring output signal of the wavelength monitoring mechanism is fed back to a temperature controller so that the oscillation wavelength is controlled to be kept constant. Fig. 11 shows an example of a wavelength monitoring optical system using an etalon (Fabry-Perot optical resonator) (for example, see IEEE Photonic Technology Letters, Vol.11, No.11, p.1431, 1999). The left side of a semiconductor laser (LD) 10 located in the center is a so-called front side which shows an optical system for transmitting an optical signal. An optical signal made to exit from a front end surface of the LD 10 is coupled to an optical fiber 50 by use of a lens system 80 so as to be transmitted. The right side of the LD 10 is a so-called back side which shows an optical

system for monitoring the oscillation wavelength of the LD.

Beam emitted from a rear end surface of the LD 10 is used for monitoring the wavelength. The beam emitted from the LD 10 is collimated as parallel beams by a collimator lens 82, so that

5   the parallel beams enter the etalon 84. The beams transmitted through the etalon 84 are condensed into a photo detector 30 by a condenser lens 86. The resonator length of the etalon 84 is adjusted so accurately as to correspond to the wavelength to be monitored. When the wavelength fluctuates, the quantity

10   of transmitted beam fluctuates. Hence, the change of the quantity of transmitted beam is detected as the fluctuation of the output of the photo detector 30. An output signal of the photo detector 30 is fed back to a temperature controller (not shown) of the LD 10 to thereby make it possible to suppress the fluctuation

15   of the oscillation wavelength of the LD 10. Instead of the etalon, an optical device having a spectroscopic function or a filter function may be used for detecting the wavelength fluctuation. Examples of the optical device are an optical filter, an optical fiber-Bragg diffraction grating, etc.

20   As described above by way of example, the background-art wavelength monitoring apparatus is constituted by an optical system for collimating beam emitted from the LD and making the collimated beam incident on a photo detector through an optical device. In such an optical system, optical parts such as a lens,

25   and so on, are required for bringing effective optical coupling.

Moreover, accurate adjustment is required. Hence, it is difficult to reduce the size of the apparatus as a whole. Moreover, the number of parts increases. Hence, there is a problem that it is difficult to retain stability against the fluctuation of

5   temperature and the change of environment such as a shock.

SUMMARY OF THE INVENTION

To solve the aforementioned problem, an object of the present invention is to provide a wavelength monitoring apparatus which is small-sized and which can be used without adjustment.

10   The wavelength monitoring apparatus according to the present invention is constituted by an optical device made of a periodic mutilayer structure; a beam source optically connected to at least one end surface of the multilayer structure, the one end surface being not parallel to layer surfaces of the mutilayer

15   structure; and a beam detecting means provided for detecting beam made to exit from at least one surface of the multilayer structure at a specific angle with respect to a specific wavelength, the one surface being parallel to the layer surfaces of the mutilayer structure.

20   As an embodiment of the optical device made of a periodic multilayer structure, the optical device is made of a multilayer film formed on a substrate transparent to the wavelength used. A semiconductor can be used as the beam source. A photo detector can be used as the beam detecting means.

25   In this case, it is preferable that the semiconductor laser

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and the photo detector are integrated on a substrate on which the multilayer film is formed. On this occasion, beam emitted from the semiconductor laser can be coupled to a beam incidence end surface of the multilayer film by level differences provided on the substrate on which the multilayer film is formed. In addition, the photo detector can be provided on a surface opposite to the surface of the substrate on which the multilayer film is formed.

In the wavelength monitoring apparatus according to the present invention, the fluctuation of the wavelength is detected as a change of the exit angle by the operation of the periodic multilayer structure which functions as one-dimensional photonic crystal. Because the change of the exit angle on the basis of the fluctuation of the wavelength is very large, for example, compared with that in a background-art diffraction grating or the like, the size of the apparatus can be reduced as a whole. In addition, because such a periodic multilayer structure is generally formed on a substrate, the periodic multilayer structure is suitable for integration of the beam source and the beam detecting means on one and the same substrate. Hence, optical parts such a lens, and so on, are not required, so that a wavelength monitoring apparatus small in size and excellent in stability can be provided.

The present disclosure relates to the subject matter contained in Japanese patent application No. 2000-391817 (filed on December 25, 2000), which is expressly incorporated herein by reference

in its entirety.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a typical view showing an effect of a periodic multilayer structure which is the base of the present invention.

Fig. 2 is a view showing the basic configuration of the periodic multilayer structure.

Fig. 3 is a view showing a refractive angle of beam incident onto a homogeneous thin film layer.

Fig. 4 is a view showing an example of photonic band graphs in the periodic multilayer structure.

Fig. 5 is a view showing the relation between guided beam and refracted beam in a third band of the periodic multilayer structure.

Fig. 6 is a view showing an embodiment of a wavelength monitoring apparatus according to the present invention.

Fig. 7 is a view showing a mode in use of the wavelength monitoring apparatus according to the present invention.

Fig. 8 is a view showing another mode in use of the wavelength monitoring apparatus according to the present invention.

Fig. 9 is a view showing a further mode in use of the wavelength monitoring apparatus according to the present invention.

Fig. 10 is a view showing a still further mode in use of the wavelength monitoring apparatus according to the present invention.

Fig. 11 is a view showing the configuration of a background-art

apparatus for monitoring the wavelength of a semiconductor laser.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A mode for carrying out the present invention will be described below specifically.

5　　　Among optical function devices, an optical device, in which a multilayer film formed from thin films each having a thickness equal to or smaller than the wavelength of beam and laminated on a substrate such as a quartz substrate or a glass substrate is used as an anti-reflection film, a polarization separating

10　filter, a wavelength selective filter, or the like, has been already put into practical use and has been used widely.

In most cases, use of such an optical multilayer film is generally conceived upon the assumption of beam rays which pass through the uppermost layer surface to the lowermost layer surface

15　of the multilayer film provided on a surface of the substrate. There is none but the following example as an example in which an end surface of the multilayer film, that is, a surface where the periodic structure is exposed, is used as a beam incidence surface or as a beam exit surface.

20　　　Theoretical analysis in a direction of beam rays incident on a section of an inclined multilayer film has been described (Applied Physics B, Vol.39, p.231, 1986). The fact that the same polarization separating effect as that of a birefringent material is obtained by use of properties (so-called structural

25　birefringence) of the multilayer film the refractive index of

which varies in accordance with TE and TH polarized beam has been disclosed to attempt separation of polarized beam due to structural birefringence (Optics Letters Vol.15, No.9, p.516, 1990). There has been further a report that the periodic multilayer film is regarded as one-dimensional photonic crystal for obtaining very large dispersion (super-prism effect) because the first band is shaped linearly in a neighbor of the band gap ("International Workshop on Photonic and Electromagnetic Crystal Structures" Technical Digest, F1-3).

The inventors of this application suggested by fruits of those basic studies have devised an optical device as follows.

Fig. 1 is a sectional view typically showing an optical device according to an embodiment of the present invention. A multilayer film 1 having periods is formed on a surface of a parallel and planar transparent substrate 2. For example, the multilayer film is provided as a structure in which materials A (refractive index: n_A) each having a thickness t_A and materials B (refractive index: n_B) each having a thickness t_B are laminated alternately with $\underline{a} = (t_A + t_B)$ as a period.

According to the inventors' experiment, when laser beam (incident beam) 3 with a wavelength λ is made incident on an end surface 1a of the multilayer film 1 after the end surface 1a is polished, a large part of beam serves as guided beam 4 in the inside of the multilayer film 1. A part of beam, however, serves as beam 5 leaked to the substrate 2 side. The direction

(angle θ) of the leaked beam 5 is approximately constant with respect to the wavelength λ, so that the leaked beam 5 forms luminous flux with very good directivity. Moreover, because the value of θ varies largely in accordance with the value of λ, the multilayer film 1 can detect the change of the wavelength of the incident beam 3 as a change of the angle θ with high sensitivity.

The principle of the aforementioned phenomenon will be described in brief.

Fig. 2 is a perspective view showing an example of the periodic multilayer structure 100 which is a subject of the present invention. Materials A each having a refractive index n_A and a thickness t_A and materials B each having a refractive index n_3 and a thickness t_B are laminated stratiformly alternately in a Y direction. Boundary surfaces between respective layers and a surface 100b are parallel to one another in an (X, Z) plane. Here, the boundary surfaces and the surface 100b are generically called "layer surfaces". The period $\underline{a}$ in the multilayer structure is equal to $(t_A + t_B)$.

When analysis is made as to how beam with a wavelength λ is propagated in the periodic multilayer structure 100 when the beam is incident on the end surface 100a (not parallel to the layer surfaces) of the periodic multilayer structure 100, it is found that the periodic multilayer structure 100 under a predetermined condition serves as so-called photonic crystal

to thereby exhibit an effect peculiar to the propagated beam.

A method for expressing refraction of beam in a boundary between two media each homogeneous in refractive index by means of plotting will be described with reference to Fig. 3. Beam rays R_A, which advance along the vicinity of the medium A side boundary surface between the medium A with a refractive index n_A and the medium B with a refractive index n_B ($n_A < n_B$) so as to be parallel to the boundary surface, are emitted, as refracted beam R_B with an angle θ, to the medium side B.

This angle θ can be obtained on the basis of a graph plotted by use of two circles C_A and C_B with radii proportional to n_A and n_B respectively. As shown in Fig. 3, circles C_A and C_B are plotted. A vector having a direction corresponding to the beam rays R_A is plotted as a line normal to the circle C_A. A line parallel to a line connecting the centers of the two circles C_A and C_B is plotted from a point on the circle C_A to thereby obtain a point of intersection with the circle C_B. A vector plotted from this point of intersection in the direction of a line normal to the circle C_B shows the direction of refracted beam R_B. This circle C_A corresponds to the most basic photonic band in the case where beam with a wavelength λ propagates in a homogeneous material A.

A band graph for the periodic multilayer structure can be obtained by calculation on the basis of the principle of photonic crystal. The method of calculation has been described in detail

in "Photonic Crystals", Princeton University Press, 1995, Physical
Review B Vol.44, No.16, p.8565, 1991, or the like.

Assume that the periodic multilayer structure 100 in Fig.
2 has a periodic structure which is continuous infinitely in
the Y direction (lamination direction) and is extended infinitely
in the X and Z directions (the directions of spreading a plane).

Fig. 4 shows results of band calculation by a plane wave method,
upon first, second and third bands of TE-polarized beam with
respect to a plurality of wavelengths in the multilayer structure
having a structure in which two kinds of layers represented by

$$n_A = 1.44 \ (t_A = 0.5a) \text{ and}$$

$$n_B = 2.18 \ (t_B = 0.5a)$$

are laminate alternately with a period of $\underline{a}$. Respective drawings
in Fig. 4 show Brillouin zones each representing one period in
a reciprocal space. The vertical axis represents the Y-axis
direction in which the upper and lower boundaries express the
range of $\pm\pi/a$ from the center. The horizontal axis represents
the Z-axis direction (or the X-axis direction) which has no boundary
because the Z-axis direction is an aperiodic direction. The
left and right ends in each of the graphs shown in Fig. 4 are
provided to show the range of calculation for convenience' sake.

In each Brillouin zone, a position means a wave vector in the
multilayer structure, and a curve means a band corresponding
to the wavelength λ (in a vacuum) of incident beam. Incidentally,
numerical characters given to curves respectively in Fig. 4 are

values of the ratio of cycle to wavelength (a/λ) in the multilayer

structure. In a band graph of the periodic multilayer structure,

discontinuity (so-called photonic band gap) occurs when a/λ is

larger than a certain value.

5   Fig. 5 shows the third band having the relation between

guided beam in the Z-axis direction and refracted beam (leaked

beam) thereof toward the medium tangent to the surface of the

multilayer structure when incident beam 3 with a wavelength λ

enters the periodic multilayer structure. Because beam rays

10   in the multilayer structure can be expressed as lines normal

to curves shown in the band graph, the guided beams in the Z-axis

direction in thethird band can be expressed as 3A and 3B in Fig.

5. According to the inventors' research, the intensity of the

guided beam 3B is larger than that of the guided beam 3A. Each

15   of the guide beams is made to exit as refracted beam from the

boundary surface between the multilayer structure and the medium

tangent to the surface of the multilayer structure. To emit

the refracted beam, however, it is necessary that the refractive

index of the medium expressed by the radius of each circle is

20   higher than a predetermined value as is obvious from Fig. 5.

The angle θ of refracted beam with respect to the corresponding

guided beam is kept approximately constant. Hence, it is expected

the exit beam serves as luminous flux with very good directivity.

Because the value of θ varies largely in accordance with the

25   wavelength λ of incident beam, high-resolving-power wavelength

separation can be achieved. Hence, the multilayer structure configured as shown in Fig. 1 can be applied to a sensitive wavelength monitoring apparatus.

The periodic multilayer structure is not limited to the configuration owing to two kinds of materials as shown in Fig. 2. Three or more kinds of materials may be provided. It is, however, necessary to laminate the materials so that the refractive indices and thicknesses the respective layers have predetermined periodicity. The periodic multilayer structure is generally constituted by a laminate of n (n is a positive integer) kinds of materials. Assume that the refractive indices of materials 1, 2, …, n forming one period are replaced by n_1, n_2, …, n_n respectively. Assume that the thicknesses of the materials 1, 2, …, n are replaced by t_1, t_2, …, t_n respectively. The average refractive index n_M per period of the multilayer structure with respect to the wavelength λ used is defined as follows:

$$n_M = (t_1 \cdot n_1 + t_2 \cdot n_2 + … + t_n \cdot n_n)/a$$

in which a is one period given by the following expression:

$$a = t_1 + t_2 + … + t_n$$

The condition concerning the average refractive index of the multilayer structure and the period of the multilayer structure suitable for the present invention can be given by the expression:

$$0.5\lambda/n_M \leq a$$

If this condition can be satisfied, the effect of photonic crystal can be fulfilled because a/λ is larger than the band gap formed

in the direction of lamination and near $0.5\lambda/n_M = a$. If the period
$\underline{a}$ is smaller than the range represented by the above condition,
the characteristic of the multilayer structure becomes near to
that of a homogeneous medium with the average refractive index.

5   The above description has been made upon the fact that the
operation of the wavelength monitoring apparatus can be achieved
when the periodic multilayer structure is used so that beam is
made incident on the structure in a direction perpendicular to
the direction of periodicity of the structure.

10   The configuration of the apparatus for monitoring the
wavelength of a semiconductor laser (LD) by use of the
aforementioned function will be described below. A core layer
and a clad layer are epitaxially grown on a substrate by a suitable
method such as an MOCVD method or an MBE method to thereby produce
15   the LD. Laser beam can be made to exit from an end surface or
a front surface of a film in accordance with the device structure
of the LD. Although the laser of the type of emitting laser
beam from an end surface is described here, the laser need not
be limited to this type.

20   Beam made to exit from an end surface of the LD has an elliptic
beam pattern. In use of such beam, generally, the beam needs
to be condensed by use of a coupling device such as a lens.
However, when such beam is to be coupled to a device having a
waveguide structure, the beam exit end surface of the LD may
25   be brought sufficiently near to the beam incidence end surface

of the device so that coupling loss can be reduced to about 4 dB (see IEICE Trans. Electron., Vol.E80-C, No.1, p.107, 1997).

In the present invention, the LD is disposed near to the multilayer film to perform optical coupling so that a condensing optical system through a lens can be omitted to reduce the size of the apparatus. Of course, beam emitted from the LD may be condensed by a condensing optical system such as a lens or the like so that the beam can be made incident on an end surface of the multilayer film.

A signal transmission optical fiber, a semiconductor laser or the like may be integrally disposed in accordance with various guide grooves produced accurately on a substrate so that the optical axes of respective parts can be made coincident with one another without alignment. Because the number of parts is so small that adjustment is little required, the purpose of wavelength monitoring can be achieved steadily and accurately.

In such configuration, a compact low-cost LD beam source module having an optical signal transmission optical system integrated as well as the wavelength monitoring optical system can be achieved.

A specific configuration example will be described below.

As shown in Fig. 6, a 0.3 mm-thick silicon substrate 12 was processed so that a guide groove 13 for an optical fiber 50, a groove 14 for mounting an LD, and a terrace 15 for forming a multilayer film were formed in the silicon substrate 12. When the multilayer film 1 was to be formed on the multilayer film-forming

terrace 15, a level difference 16 was designed to be provided

between the terrace 15 and the LD mounting groove 14 so that

the central height of an end surface 1a of the multilayer film

1 was level with the height of an active layer 11 of the LD.

5   A silica layer having a thickness of about 10 μm was deposited

on the surface of the silicon substrate 12 in the terrace portion

15 so as to be used as a buffer layer. A thin film of titanium

oxide (thickness t_2 = 470 nm) and a thin film of silica (thickness

t_1 = 470 nm) were formed successively on a surface of the buffer

10   layer so as to form one period. This operation was repeated

by 20 periods (40 layers) in total.

In this case, because leaked beam 5 was made to exit from

the silicon substrate 12 side, a photodiode (photo detector,

hereinafter abbreviated to "PD") 30 sensitive to a target

15   wavelength to some extent was fixed to a rear surface 12b of

the substrate 12 by an adhesive agent or the like so as to form

a beam detecting means for monitoring the wavelength. The PD

30 was located in a position onto which the leaked beam having

an exit angle θ of about 75° was incident, as shown in Fig. 6.

20   Further, an InGaAsP/InP type LD having a wavelength λ near 1.3

μm was used as the LD 10. Incidentally, the leaked beam may

be also sent out toward the air side above the multilayer film

1. In order to improve the intensity of the leaked beam on the

substrate side, an optical refection layer 17 may be provided

25   on the surface 1b of the multilayer film 1. A metal thin film

or the like high in reflectance may be preferably used as the
optical refection layer 17.

When the oscillation wavelength of the LD 10 fluctuates
due to a factor such as temperature fluctuation or the like,
the position of the rear surface of the substrate 12 where the
leaked beam 5 reaches fluctuates. Hence, the output current
of the PD 30 varies accordingly. When the current fluctuation
is monitored, wavelength fluctuation of the LD 10 can be monitored.

Fig. 7 shows the relation between the beam intensity detected
by the PD 30 and the incident wavelength. Assuming now that
beam having a wavelength λ is incident on the end surface 1a
of the multilayer film 1, leaked beam 5 having a specific exit
angle θ is generated. A PD 30 is mounted on a rear surface 12b
of the substrate 12 in the position where the leaked beam 5 reaches.
When the wavelength of the LD changes by $\Delta\lambda$ due to somewhat
factor such as temperature fluctuation or the like, the exit
angle of the leaked beam 5 from the multilayer film 1 changes
by $\Delta\theta$. For this reason, the output current of the PD 30 having
a definite beam-receiving surface changes in accordance with
the change of the quantity of the incident beam. On this occasion,
the relation between the output current of the PD 30 and the
wavelength λ is shown in Fig. 7. That is, when fluctuation in
the output current of the PD is monitored, a situation as to
how the wavelength of LD 10 fluctuates can be found. For example,
in the case of Fig. 7, as the output current of the PD increases,

that is, as the beam intensity increases, it is found that the wavelength of the LD 10 is shifted to a long wavelength side. On the other hand, as the output current of the PD decreases, it is found that the wavelength of the LD 10 is shifted to a short wavelength side. Because it is found on the basis of such information that shifting of the wavelength of the LD 10 to the short wavelength side means the fall of the temperature of the LD 10, a signal for instructing a temperature controller to raise temperature can be sent to the temperature controller to thereby adjust the wavelength of the LD 10. On the other hand, when the wavelength of the LD 10 is shifted to the long wavelength side, a reverse operation can be performed.

Further, two PDs 31 and 32 may be mounted adjacently as shown in Fig. 8. A ratio between output currents of the two PDs with respect to a normal wavelength is measured in advance. The ratio is preferably as near as 1:1. The ratio is monitored because the ratio fluctuates due to wavelength fluctuation. When only one PD is used for monitoring the absolute value of the output current, a cause of the output current fluctuation due to another factor such as temperature fluctuation than wavelength fluctuation cannot be identified. When the ratio between the outputs of the two PDs is used, the influence of temperature fluctuation or the like on output fluctuation can be removed.

Further, another applied example will be described. When

beams having wavelengths $\lambda 1$, $\lambda 2$, … are incident on an end surface
1a of an optical device constituted by a multilayer film 1, leaked
beams 5-1, 5-2, … having different exit angles are generated.
As shown in Fig. 9, a plurality of PD 30-1, 30-2, … are mounted
5   on a rear surface 12b of a substrate 12 in positions where the
leaked beams reach.   On this occasion, the relation between each
of output currents of three adjacent PDs 30-(i-1), 30-i and 30-(i+1)
and the wavelengths λ is shown in Fig. 9.   Because the leaked
beam 5-i with a wavelength λi reaches the central position of
10 the PD 30-i but is hardly incident on the PDs 30-(i-1) and 30-(i+1)
on the opposite sides of the PD 30-i, there are remarkable
differences in intensity among beams detected by the PDs.
Therefore, when a specific current level IL is determined as
shown in Fig. 9 and compared with the output current of each
15 PD, detection can be made as to whether a beam with a predetermined
wavelength has reached the PD or not.   Of course, the number
of photodiodes may be increased in accordance with the number
of wavelengths and the photodiodes may be arranged into the form
of an array so that a plurality of wavelengths can be monitored.
20   Because the leaked beam from the multilayer film has strong
directivity, the leaked beam reaches a very narrow range.   When
the width of the multilayer film is narrowed in advance, a slit
effect can be also expected.
        Although each of the above examples has been described upon
25 the case where a periodic multilayer structure is achieved by

a multilayer film, it is also possible to produce a periodic

structure perpendicular to a substrate and apply the periodic

structure to a periodic multilayer structure as shown in Fig.

10. Such a structure can be produced by a microprocessing technique.

5   A specific method thereof will be described.

A photo resist is applied on a silicon substrate 22 and

a photo mask is used so that a plurality of stripe-like patterns

each having a desired interval and a desired thickness are exposed

to beam and developed. The silicon substrate 22 masked with

10 the photo resist patterns is etched with a suitable etching solution,

so that a periodic multilayer structure 20 constituted by a

combination of layers of silicon and layers of air perpendicular

to the substrate 22 can be formed. An LD 10 is mounted on a

substrate 22 so that exit beam can be coupled to an end surface

15 20a of the periodic multilayer structure 20. A groove 13 for

fixing an optical fiber 50 into a predetermined position and

a guide (not shown) used for positioning the LD 10 may be formed

in and on the substrate.

When beam emitted from the LD 10 is made incident on the

20 end surface 20a of the periodic multilayer structure 20, exit

beam (leaked beam) 25 can be obtained at a specific angle θ to

a surface 20b of the periodic multilayer structure 20 and in

a direction parallel to the substrate 22. A PD 40 is mounted

in a direction in which exit beam having a predetermined wavelength

25 is made to exit. Preferably, the PD 40 is of a waveguide type.

A plurality of PDs may be mounted in accordance with the purpose, similarly to the case of the multilayer film. A guide for determining the position of the PD 40 may be produced, similarly to the case of the LD. Further, a lens for condensing the leaked

5   beam may be produced on one and the same substrate. In such configuration, because the exit beam 25 becomes parallel to the substrate 22, all the devices can be integrated on one and the same substrate to thereby bring further reduction in size of the apparatus.

10   As described above, in accordance with the present invention, a wavelength monitoring apparatus sensitive to a wavelength can be achieved without increase in apparatus size by use of the fact that beam leaked from a periodic multilayer film has good directivity and that the direction of the leaked beam has strong

15   wavelength dependence. Because such multilayer films can be mass-produced relatively inexpensively by use of an existing technique, reduction in price of these optical devices can be attained. In addition, more compact devices can be formed by use of a microprocessing technique.

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